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Invention: INTEGRATED OPTICS SAMPLING DEVICE AND ITS FABRICATION METHOD

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☐ Regular Utility Application

☐ Continuing Application
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☐ PCT National Phase Application

☐ Design Application

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SPECIFICATION

INTEGRATED OPTICS SAMPLING DEVICE AND ITS FABRICATION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is the U.S. National Phase of International Application No. PCT/FR03/50174, filed December 15, 2003, which, in turn, claims priority from French Application No. 02-15918, filed December 16, 2002, the entire contents of both applications being hereby incorporated by reference.

Field of Invention

[0002] This invention relates to an integrated optics sampling device as well as the fabrication method of this element.

Description of Related Art

[0003] Currently, to sample a light wave, a coupler or a divider is generally used.

[0004] Parameters of the coupler are set to sample from a light wave transmitted in a wave guide, while the parameters of the divider are set to divide the initial light wave into determined parts.

[0005] Figure 1 shows a block diagram, of a conventional linear filter associated with a conventional sampling device for spectral checking of filtering.

[0006] A source 2 is represented in this figure. The source 2 emitting emits a light wave E of intensity I_0 in a thin spectral band assimilated to a single wavelength. A sampling device 4 (a coupler for example) receives this signal of intensity I_0, sampled at I_1, with a sampling rate γ and transmits a signal with an intensity I_0' to the linear filter 8. The output signal of the filter has an intensity I_2 such that a

ratio between the signal I_2 output from the filter and the sampled signal I_1 is expressed as follows:

$$I_2/I_1 = \frac{1-\gamma}{\gamma} \times (a \times d\lambda + t_m)$$

[0007] where $d\lambda = \lambda-\lambda_m$ for a filter 8 of slope a around a central wave length λ_m and with a value t_m at this wavelength.

[0008] The signal I_2 measured at the filter output is therefore proportional to the emission wave length. If the wavelength changes, it is possible for example to correct this variation by servo controlling the spectral position of the source on the preceding measurement.

[0009] Even though this may be satisfactory in certain respects, these devices comprise separate sampling and filtering elements which induce losses and make the complete system more complex.

[0010] Furthermore, in the field of filters, an incident light wave is generally separated into two components, one of which is transmitted and the other is not, at distinct spectral intervals, at the component output. For certain applications, it may be useful to measure and/or check the part of the wave not transmitted.

[0011] In the field of optical fibres, to recover the part of the wave not transmitted, a detection element is used at the edge of the optical cladding. On this subject, one can refer to the patent WO/0216979.

[0012] Figure 2 shows diagrammatically an example of this type in the case of a an optical fibre filter formed for a long period grating.

[0013] Figure 2 is a partial cross section of an optical fibre 1, comprising a core 3, an optical cladding 5 surrounding the core and a grating 7 made in a part of the core 3.

[0014] This cross section is in a plane which contains the direction z of propagation of the light wave in the core.

[0015] The grating 7 is configured to provide a zone of interaction between the core and the cladding and to couple in the cladding, a part C (the coupled wave) of an initial light wave E. The coupled wave C in the cladding is shown diagrammatically by arrows. At an output of the zone of interaction, the core transports a part S of the non coupled wave in the cladding.

[0016] After the zone of interaction, a detection element D such as a photo-detector, is positioned at an edge of the optical cladding.

[0017] In the optical fibres, because of the construction dependency between the core and the cladding the detection element can only be positioned at the edge of the cladding, if the propagation of the wave in the core is not to be disrupted. The axis of the detector is perpendicular to the direction of propagation of the signal in the cladding. Consequently, only a part of the guided signal in the cladding is detected.

[0018] To improve the detection, it can be envisaged, as shown in Figure 2, to create a cavity 6 in the fibre cladding to insert the detector. However, the detection element may still not be able to detect the entire guided signal in the cladding. In addition, the cavity machined in the cladding may render the component more fragile.

BRIEF SUMMARY OF THE INVENTION

[0019] An aspect of an embodiment of this invention is to provide an integrated optics sampling device which permits overcomes the problems of the prior art.

[0020] For example, the sampling device according to an embodiment of the invention allows part of a light wave to be sampled for filtering. This allows to avoid the problems

related to couplers and dividers and permits, when using a cladding that is independent of a guide core, to recover the complete signal sampled at an output of the device.

[0021] Specifically, the sampling device according to an embodiment of the invention comprises a substrate, a wave guide core capable of transporting a light wave in the substrate and an optical cladding. At least one portion of the cladding surrounds at least one portion of the core in a zone of interaction. The zone of interaction comprises a grating configured to couple part of the light wave in the cladding. The coupled part of the wave, i.e., the coupled wave, the refractive index of the cladding is different from the refractive index of the substrate. The refractive index of the cladding is lower than the refractive index of the core, at least in a part of the cladding adjacent to the core in the zone of interaction.

[0022] By surrounding, it is meant that the fundamental profile mode of the guide core has a maximum intensity that is included in the index profile of the cladding. In this way, the profile of the fundamental mode of the core may be totally or partially included in the index profile of the cladding. This translates (at structural level) in having a core located anywhere in the cladding, including at its edge. In that case, the core may be partially outside of the cladding.

[0023] The cladding of the sampling device of the invention is generally associated with at least one recovery and treatment element so as to recover and treat all or part of the coupled wave. This element will be called the first recovery and treatment element.

[0024] The first recovery and treatment element associated with the device according to an embodiment of the invention permits the recovery and then treatment of all or part of the coupled wave. The coupled wave is the complementary part of the non coupled wave, with respect to

the initial wave. Knowing the initial wave characteristics and the coupled wave characteristics allows one to determine the characteristics of the non-coupled wave. The non-coupled wave is, in general is a useful part of the light wave.

[0025] However, it must be appreciated that the sampling device may be associated to a second recovery and treatment element in order to recover and treat directly all or part of the non coupled wave of the core.

[0026] According to an embodiment of the invention, the core of the guide has a refractive index n_c and the optical cladding has a refractive index n_g such that $n_c > n_g$. Furthermore, a grating is created in the zone of interaction to couple at least one guided mode in the core, to one or more cladding modes. The cladding modes spread in the same direction as the core modes.

[0027] The coupling between the different modes takes place for a spectral band of central wave length λ_j. By spectral band it is meant a band with a set of wavelengths with a central wavelength and a determined bandwidth. A light wave can comprise one or more spectral bands.

[0028] For example, in the case of long period gratings, the coupling for an elementary grating between the different modes takes place for determined wave lengths λ_j given for the following known relationship:

$$\lambda_j = \Lambda \times (n_0 - n_j) \qquad (1)$$

[0029] where:

[0030] n_0 is the effective index of a guided mode in the core,

[0031] n_j is the effective index of the cladding mode number j,

[0032] λ_j is the resonance wave length for the coupling in mode j,

[0033] Λ is the period of the grating.

[0034] Generally speaking, the coupling results in an energy transfer between the guided mode(s) in the core and the cladding mode(s) for the wavelengths λ_j. The energy coupled in the cladding modes then spreads in the cladding (the cladding may be assimilated to a large specific guide) and the non coupled energy continues to spread in the core. The non-coupled energy has a power spectrum with energy losses for the wavelengths λ_j on spectral bands called filtering bands.

[0035] When there is only a relatively small difference between the effective indices n_0 and n_j (a few 10^{-2} to a few 10^{-3}) and the range of wavelengths of concern in the optical guiding is around 1.5 µm, the relationship (1) shows that the grating periods are around a few dozen µm to a few thousands of µm.

[0036] The zone of interaction thus permits to filter spectrally part of the initial wave. The filtered part which is called the coupled or sampled part of the initial wave is then transported by the cladding while the non-filtered part remains in the guide core.

[0037] The fabrication of the integrated optics sampling device allows to form in the substrate a wave guide core independently of the cladding and vice versa.

[0038] By independence of the core and the cladding, it is meant that the core and the cladding can exist in a substrate independently from one another. In other words, the core can exist without the cladding and the cladding can exist without the core, contrary to fibres.

[0039] The independence of the core and the cladding allows more possibilities than in optical fibres. Hence, outside the zone of interaction, the cladding may no longer surround the core, which allows to have two distinct optical channels respectively formed for the core and the cladding. The cladding only influences the propagation of a light wave

in the associated guide core in the part which surrounds the core and the cladding can guide or transport light waves independently of the core.

[0040] The spatial separation of the core and the cladding permits the coupled signal to be recovered directly or indirectly without any risk of interference with the non coupled signal propagating in the core.

[0041] The first recovery and treatment element may thus be optically connected to one end of the cladding more easily, without being impeded by the core in order to recover all or part of the coupled wave in the cladding depending on the applications sought.

[0042] According to one embodiment of the invention, the first recovery and treatment element comprises an optical element which may be a measuring element, positioned directly at one end of the cladding to measure the filtered wave.

[0043] According to a second embodiment of the invention, the first recovery and treatment element comprises a second zone of interaction and an optical element which may be, for example, a measuring element. The second zone of interaction is formed in the substrate, by a second guide core situated in a portion of the cladding and by a grating capable of coupling, in the second guide core, the coupled wave which spreads in the cladding. The guide core is optically connected to the optical element outside of the second zone of interaction.

[0044] The cladding does not necessarily have a uniform structure. In particular, the section of the cladding in the first zone of interaction may be larger than the section of the cladding of the second zone of interaction. Consequently, the section of the cladding between these two zones of interaction can be variable. Furthermore, the first and the second cores may be decentred with respect to each other in the cladding.

[0045] The characteristics of the second zone of interaction are however most often the same as those of the first zone of interaction as a function of the second zone, is to re-couple the coupled wave in the cladding, in the second core.

[0046] In either the first embodiment or the second embodiment of the invention, it is possible to place at one end of the guide core the second recovery and treatment element, in order to recover and treat all or part of the non-coupled wave in the cladding. In this instance, the sampling device can be associated with two recovery and treatment elements which can allow a double detection to be implemented: a detection of the coupled signal in the cladding and a detection of the non-coupled signal.

[0047] The first and/or second recovery and treatment element comprise(s) at least one optical element which can be, for example, a measuring element such as a photo-detector or a group of photo detectors, capable of characterising at least spectrally the wave measured. Alternatively, the optical element can be a suitable optical element for the application in question. The optical element can be associated with a formatting element such as a lens, a lens fibre. The formatting element allows to target the wave to be measured on the photo-detector.

[0048] According to a third embodiment of the invention, in which the core and the cladding are not separated after the zone of interaction, the first and the second recovery and treatment elements form a single recovery and treatment element. The single recovery and treatment element comprises a matrix of optical elements such as photo-detectors with optionally an optical adaptation device. Part of the matrix is configured to permit the coupled wave to be recovered and possibly measured. The other part of the matrix permitting is

configured to permit the wave non coupled to be recovered and possibly measured.

[0049] The independence of the core and cladding, the size of the cladding can be adapted to a given matrix of detectors. This is not possible in the optical fibres which in particular have the disadvantage of a circular cladding and thus are poorly adapted to the form of the matrix in lines and columns.

[0050] The characteristics of the one or more zones of interaction are determined following the one or more spectral bands of the wave that are to be sampled for coupling.

[0051] The efficiency of the coupling between the modes depends on the length of the grating and the coupling coefficient K_{0J} between 0 and j modes. This coefficient is provided by the spatial recovery integral of the 0 and j modes, weighted by the index profile induced for the grating. The following relationship of the type:

$$K_{0J} \propto \iint \xi_0 . \xi_J^* . \Delta\Delta n s \quad (2)$$

[0052] is obtained where:

[0053] ξ_0 and ξ_j are the transversal profiles of the 0 et j modes, and ξ_j^* is the conjugate complex of ξ_j,

[0054] Δn is the amplitude of the effective index modulation induced for the grating in a plane perpendicular to the direction of propagation of the wave,

[0055] ds is an integration element in a plane perpendicular to the axis of propagation of the wave.

[0056] The modification of K_{0j} is obtained by varying the profile of the modes and/or the induced index profile of the grating. In other words, the modification of K_{oj} is obtained by varying the opto-geometrical characteristics of the cladding and/or of the core (dimensions, index level, etc.)

and/or the characteristics of the grating (Δn, position of the grating with respect to the core and the cladding, etc.).

[0057] In general, to modify the characteristics of the zones of interaction, the following parameters may be varied:

[0058] the length L of the grating,

[0059] its period Λ,

[0060] the amplitude of the effective index modulation induced for the grating Δn,

[0061] the index of the core n_{co},

[0062] the phase of the grating ϕ.

[0063] According to an embodiment of the invention, the cladding is created artificially in the substrate, at least in the one or more zones of interaction and independently of the core and the substrate.

[0064] Generally speaking, we will call artificial cladding this type of cladding and artificial cladding grating (ACG), a zone of interaction.

[0065] The substrate can be created from a single material or from the superposition of several layers of materials. In this case, the refractive index of the cladding is different from the refractive index of the substrate, at least in the layers next to the cladding.

[0066] Each cladding has a refractive index higher than that of the substrate.

[0067] According to an embodiment of the invention, the integrated optics guide may be a planar guide, when the light is confined in a plane containing the direction of propagation of the light or a micro guide, or when the light is confined in two directions that are transversal to the direction of propagation of the light.

[0068] Furthermore, the grating of a zone of interaction can be formed in the core of the guide and/or in the cladding and/or in the substrate. A grating may comprise a succession

of elementary gratings. It may be periodic or pseudo-periodic.

[0069] Thus, for example for a cladding, the bigger its dimensions and index level are, the higher the number of cladding modes are allowed to spread. As a result, more spectral filtering bands will be possible. This can be useful if multiple filtering is intended or to have more choice in the selection of a filtering mode.

[0070] On the other hand, if the aim is to limit the number of cladding modes that can be coupled, it is on the contrary better to reduce the opto-geometrical dimensions of the cladding.

[0071] With respect to the core, its dimensions and index level determine the characteristics of the mode that spreads therein. Furthermore, the higher the differences of index between the core, the cladding and the substrate, the more chance there is to potentially have couplings for low grating periods as shown by the equation (1) (at a wavelength of given resonance, the period is inversely related to the difference of index between the guided mode of the core and the cladding mode).

[0072] By modifying the position of the core, the grating and the cladding, different couplings may be generated. Indeed, it can be seen clearly from equation (2) that the coupling force depends on the relative position in the transversal plane (relative to the axis of propagation) of the profiles of the cladding mode, of the guided mode in the core and of the grating.

[0073] The sampling device according to an embodiment of the invention may be used with many optical components. It is particularly useful in the case of filtering components such as linear filters or gain flatteners used for example with optical amplifiers.

[0074] In addition, the invention has applications in all fields where the sampling of a light wave is used, for example, to measure and/or check the characteristics of the wave. The present invention is , for example, especially well suited for application in the field of optical amplifiers for sampling a light wave input and/or output of an optical amplifier or even in the field of spectral filters.

[0075] According to one embodiment of the invention, the zone of interaction of the sampling device is created so that it both filters and samples. The parameters of the zone of interaction are therefore adapted to the desired filtering function, which may or may not be of the evolved type, the grating of the zone of interaction comprises at least two elementary gratings.

[0076] Thus, parameters for each elementary zone of interaction associated to an elementary grating may be selected from at least the following:

[0077] the length L of the grating or elementary gratings,

[0078] the period Λ of the grating or elementary gratings,

[0079] the profile of the grating or elementary gratings,

[0080] the position of the grating or elementary gratings in the corresponding zone of interaction,

[0081] the amplitude of the effective index modulation induced for the grating or the elementary gratings Δn,

[0082] the phase of the grating or elementary gratings ϕ,

[0083] the dimensions of the cladding which may be variable,

[0084] the dimensions of the core which may also be variable,

[0085] the value of the refractive index of the cladding which may also be variable,

[0086] the value of the index of the core in the substrate n_{co},

[0087] the position or the positions of the core in the cladding.

[0088] According to one embodiment of the invention, the cladding and/or the core of the guide and/or the grating may

be created by all types of techniques permitting the refractive index of the substrate to be modified. For example, the ionic implantation and/or radiation, for example, by laser exposure or laser photo inscription or even the depositing of layers can be used.

[0089] The ion exchange technology in glass is of interest but other substrates other than glass may be used, such as, for example, the crystalline substrates of the KTP or $LiNbO_3$ types, or even $LiTaO_3$.

[0090] More generally, the gratings may be created by all techniques permitting the effective index of the substrate to be changed. To the techniques mentioned above, we can add in particular the grating creation techniques for etching the substrate. The etching can be carried out above the cladding or in the portion of cladding of the zones of interaction and/or in the core portion of the zones of interaction.

[0091] The pattern of the grating may be obtained either by laser sweeping if radiation is used, or via a mask. A mask that may be used is the mask which is used in the fabrication of the core and/or the cladding. Alternatively, a specific mask may be used to create the grating.

[0092] The invention also relates to a fabrication method of a sampling device as previously defined. The cladding, the guide core and the grating are respectively created to modify the refractive index of the substrate so that at least in a part of the cladding next to the core and at least in each zone of interaction, the refractive index of the cladding is different from the refractive index of the substrate and lower than the refractive index of the core.

[0093] According to an embodiment of the invention, the method comprises the following steps:

[0094] a) introduction of a first ionic species in the substrate,

[0095] b) introduction of a second ionic species in the substrate,

[0096] c) burying of the ions introduced in steps a) and b),

[0097] d) creation of the grating.

[0098] The order of the steps may of course be inverted.

[0099] The introduction of the first and/or second ionic species can be made for an ionic exchange, or for ionic implantation.

[00100] The first and second ionic species may be the same or different.

[00101] The introduction of the first ionic species and/or the second ionic species may be made with the application of an electrical field.

[00102] In the case of an ionic exchange, the substrate contains ionic species capable of being exchanged.

[00103] According to one embodiment of the invention, the substrate is made of glass and contains $Na+^{+}$ ions introduced beforehand, and the first and second ionic species are Ag^{+} and/or K^{+} ions.

[00104] According to an embodiment of the invention, the step a) comprises the creation of a first mask comprising a pattern capable of obtaining the cladding. The first ionic species are introduced through this first mask. Step b) comprises the elimination of the first mask and the creation of a second mask comprising a pattern capable of obtaining the core. The second ionic species are introduced through this second mask.

[00105] According to an embodiment of the invention, the step a) comprises the creation of a mask comprising a pattern capable of obtaining the cladding and the core. The first and the second ionic species of steps a) and b) are introduced through this mask. This embodiment is in general applicable to the case in which the core and the cladding are not separated in the substrate.

[00106] The masks used in the invention are for example made of aluminium, chrome, alumina or a dielectric material.

[00107] According to an embodiment of the invention in the step c), the first ionic species is buried at least partially before step b) and the second ionic species is buried at least partially after step b).

[00108] According to an embodiment of the invention, in the step c), the first ionic species and the second ionic species are buried simultaneously after step b).

[00109] According to an embodiment of the invention, in the step c), the burying comprises a deposit of at least one layer of refractive index material, for example, lower than that of the cladding, on the surface of the substrate.

[00110] This mode may of course be combined with the two previous modes.

[00111] In an embodiment of the invention, at least a part of the burying is carried out with the application of an electrical field.

[00112] Generally before the burying under a field and/or the depositing of a layer, the process according to an embodiment of the invention may comprise among others, burying for re-diffusion in an ionic bath.

[00113] This re-diffusion step may be carried out partially before step b) to re-diffuse the ions of the first ionic species and partially after step b) to re-diffuse the ions of the first and second ionic species. This re-diffusion step may also be carried out completely after step b) to re-diffuse the ions of the first and second ionic species.

[00114] By way of example this re-diffusion is obtained by plunging the substrate in a bath containing the same ionic species as that formerly contained in the substrate.

[00115] In step d), the creation of the grating may be carried out independently of steps a) and b) or be carried out

simultaneously during step a) and/or step b) by using the same masks, for example.

[00116] Other aspects of the invention will become clearer in the following description, with reference to the figures of the appended drawings. This description is given purely by way of illustration, and is non-restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[00117] In the accompanying drawings, Figure 1 shows a block diagram of a conventional filtering device with a conventional sampling device of the prior art;

[00118] Figure 2 shows a cross section of an optical fibre with a known sampling element;

[00119] Figure 3 shows a cross section of a first embodiment of a sampling device according to an embodiment of the present invention;

[00120] Figure 4 shows a cross section of a sampling device according to an embodiment of the invention;

[00121] Figure 5 shows a section of a variant of the embodiment shown in Figure 3;

[00122] Figure 6 shows a section of a variant of the embodiment shown in Figure 4 in which the cladding has a variation of section;

[00123] Figures 7a and 7b show a cross section of a sampling device according to an embodiment of the invention;

[00124] Figure 8 shows a cross section of an example of an application of a sampling device of the invention with an amplification device;

[00125] Figure 9 shows a section of another application example of a sampling device with a filtering device according to an embodiment of the invention;

[00126] Figures 10a to 10d show a cross section of an example of the creation process of a sampling element according to an embodiment of the invention;

[00127] Figures 11a to 11d show variants of the creation of the mask pattern permitting a grating to be made according to an embodiment of the invention; and

[00128] Figure 12 shows in cross section a variant of the embodiment of the device with a grating in the cladding according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[00129] To simplify the description, by way of example, we will consider that the zone of interaction only comprises an elementary grating included in the guide core of the device.

[00130] Figure 3 shows, in a cross section, a first example of a sampling device according to an embodiment of the invention made in integrated optics.

[00131] This cross section is in a plane parallel to the surface of the substrate containing the direction z of propagation of the light wave.

[00132] This sampling device comprises in a substrate 15, a wave guide core 17, a cladding 19 and a grating 21 created by way of example in part of the core. The zone of interaction I corresponds to a zone of the substrate in which the core, the cladding and the grating are present.

[00133] As described above, the independence of the core and the cladding allows more flexibility and, in particular, to dissociate the core and the cladding. Thus, outside of the zone of interaction, the cladding can no longer surround the core. The cladding only influences the propagation of a light wave in the associated guide core in the part surrounding the core and the cladding can guide or transport light waves independently of the core. In this way, the wave transported by the cladding may be recovered more easily at one end of the cladding without being hampered by the core

[00134] As shown in this figure, the recovery and treatment element 33 can be optically connected more easily to

one end of the cladding without being hampered by the core and recover all or part of the coupled wave in the cladding depending on the applications sought.

[00135] In the embodiment of Figure 3, the cladding 19 surrounds the core 17 solely in the zone of interaction I comprising the grating 21. In other words the core 17 carrying an input light wave E, penetrates the cladding by one of its ends with the reference 19a and leaves it after the zone of interaction I by carrying a wave S corresponding to the part of the wave E that has not been coupled to the cladding in the zone of interaction. The coupled part of the wave has the reference C. The core may be connected upstream and/or downstream of the zone of interaction to optical elements (not shown) which may or may not be integrated in the substrate 15.

[00136] In this example, the input of the core 17 is optically coupled to an optical fibre 34 and at its output to an optical fibre 31 by means of ferrules, respectively, with the references 35 and 30.

[00137] To make a double detection from the sampling device shown in this figure, the fibre 31 simply has to be connected to a second recovery and treatment element (not shown). Thus, the coupled wave C in the cladding is measured at the output of the cladding by the element 33 and the complementary output wave S is measured at the output of the core 17 for the second recovery and treatment element.

[00138] In this embodiment, the recovery and treatment element 33 comprises an optical element which is, for example, a measuring element such as a photo detector (possibly associated to adaptive optics). This element 33 is positioned directly at the end 19b of the cladding. If the input of the measuring element is adapted to the end 19b of the cladding or vice versa, then all the coupled wave C in the cladding may be recovered by the measuring element.

[00139] Figure 4 shows, in a cross section, a second example of sampling device according to an embodiment of the invention.

[00140] This cross section is also in a plane parallel to the surface of the substrate and contains the direction z of propagation of the light wave.

[00141] This figure can be distinguished from Figure 3 by the recovery and treatment element which comprises a second zone of interaction I' capable of coupling the wave C spreading through the cladding 19, in a second core 24 and an optical element 26.

[00142] More precisely, the zone I' is formed in the substrate 15 by a second guide core 24 located in a portion of the cladding 19 and by a grating 23 capable of coupling in the second core all or part of the wave C spreading through the cladding. In this example, the core 24 leaves the cladding at the end 19b. The core 24 is connected to the optical element 26.

[00143] The characteristics of the second zone of interaction are most often the same as those of the zone of interaction I as its function is to couple the wave C in the second core.

[00144] This embodiment is slightly more complex than the previous one. It allows the recovery of the coupled wave on a normal sized guide. The core 24 can be connected either directly or via an optical fibre to the optical element 26.

[00145] This type of component can also be used as a multiplexer/demultiplexer in which case the core 24 is connected to an optical element depending on the application sought.

[00146] As in Figure 3, the non coupled wave transported for the core at the output of zone I can be recovered and treated.

[00147] Figure 5 shows a cross section in a plane parallel to the surface of the substrate and containing the direction z of propagation of the light wave, a variant of Figure 3. In this example, only the wave C is recovered.

[00148] This cross section can be distinguished from that of Figure 3, in that the core 17 does not leave the zone of interaction I. The non coupled wave S in the cladding is dispersed inside the cladding without being recovered, while the wave C is coupled and guided in the cladding and is recovered by the recovery and treatment element 40 connected to the end 19b of the cladding.

[00149] The optical element 33 (of Figure 3), 26 (of Figure 4) or 40 (of Figure 5) is a photo detector or a group of photo detectors, capable of characterising at least spectrally the measured wave possibly associated to a formatting element such as a lens, a lens fibre to target the wave to be measured on the photo detector.

[00150] The characteristics of the zone(s) of interaction are determined depending on the one or more spectral bands of the initial wave E that are to be filtered.

[00151] Figure 6 diagrammatically shows in a cross section in a plane parallel to the surface of the substrate and containing the direction z of propagation of the light wave, a variant of Figure 4. This figure can be distinguished from Figure 4 by the cladding 29 which creates two zones of interaction I and I'. The other elements are the same as those of Figure 4 and have the same references.

[00152] The cladding 29 has a variation of section between the two zones of interaction I and I' in order to modify the distribution of the guided modes in the cladding. Thus, each of these zones of interaction I and I' is characterized by a spectral transfer function, respectively, T1 and T2 defined for the grating selected 21, 23, the size of the core 17, 24 and the size of the cladding. In this case, the two cores 17

and 24 have the same size. The change in the size of the cladding then permits not only the position of the filtering bands to be changed separately (with respect to a fixed reference) but also relatively (of the maximums between the transfer functions).

[00153] Thus, if the pitch of the two gratings 21, 23 is adjusted so that the maximums are at the same spectral position for the two gratings, the first grating 21 will couple the fundamental mode of the core 21 to a cladding mode at the central wave length corresponding to this maximum. This mode will then be guided in the cladding 19 up to the other grating 23. The inverse coupling will then take place and the signal filtered for the grating 21 will be situated in the core 24. For the other coupled spectral bands, the cladding 19 will also guide the coupled modes to the second grating 23. However, the change of size of cladding means that the core 24 can no longer be coupled with the second grating. At the core output 24, only one of the coupled modes in the cladding can be recovered.

[00154] To modify the distribution of the guided modes in the cladding, it is also possible to decentre the core 17 with respect to the other core 24. Such a decentration permits, as previously discussed, to add a filtering element between the two zones of interaction placed in series for a common cladding.

[00155] It is also possible to combine the decentration of the two cores and the variation of the cladding section.

[00156] Figures 7a and 7b show diagrammatically the device of the invention respectively in a cross section in a plane (xz) parallel to the surface of the substrate and containing the direction z of propagation of the light wave (Figure 7a) and in a plane (yx) perpendicular to the surface of the substrate and perpendicular to the direction z of propagation of the light wave (Figure 7b).

[00157] These figures offer another solution for performing double detection. Figure 7a shows the substrate 15 having a zone of interaction I formed by the cladding 19, the guide core 17 and the grating 21. In this example, the core penetrates the cladding by the end 19a and traverse the cladding to output end 19b without being separated from the cladding.

[00158] A recovery and treatment element 50 is connected conjointly to the output ends of the core and the cladding. This element is, for example, a CCD matrix type detection unit (or a matrix detector unit) possibly associated to adaptation optics. In Figures 7a and 7b, the element 50 is a strip of detectors 51.

[00159] Figure 7b is a cross section in the plane of these detectors.

[00160] Thus, part of the input light wave E is coupled (wave C) in the zone of interaction I while the non coupled part (wave S) continues to be transported by the core 17. The concentric circles, respectively with the references C and S, diagrammatically show these waves.

[00161] The wave S is recovered by one or more detectors located in the centre of the matrix while the wave C is recovered by the other detectors.

[00162] Indeed, if the section of the cladding is large enough, the cladding mode(s) have their energies mainly distributed outside of the central zone. The distribution of the energies of the waves C and S is shown diagrammatically by way of example above the strip of detectors Figure 7b. Consequently, the central detection elements are configured to measure signal S and the other elements of the matrix are configured to measure complementary signal C.

[00163] Furthermore, the independence of the core and the cladding permits the size of the cladding to be adapted to a given matrix of detectors. While the cladding of an optical

fibre is circular and poorly adapted to the line form of the detectors.

[00164] The sampling device according to an embodiment of the invention may be used with many optical components. It is particularly useful with filtering components such as linear filters or gain flatteners used, for example, with optical amplifiers to permit the amplifier to be controlled.

[00165] Figure 8 shows precisely by way of example the use of a sampling device according to an embodiment of the invention with an optical amplifier.

[00166] This figure is in a plane yz containing the sampling device of the invention which in this example is of the same type as that of Figure 3. The optical amplifier associated to this sampling device is integrated in the same substrate 15 as the latter. It comprises an amplification element shown schematically by a shaded zone 45 which may be a spiral guide core whose input is connected to a coupler 47 and whose output is connected to the core 17 of the sampling device.

[00167] The coupler 47 comprises a first input connected to a guide core 49 from which the light wave E is introduced to be amplified and a second input connected to a guide core 51 from which a pump wave P capable of pumping the active zone 45 is introduced. The coupler 47 permits the amplifying element which is connected to the coupler output to be supplied with the waves to be amplified and pump. At the amplifier output, the core 17 thus transports the amplified wave E.

[00168] Due to the non homogeneity of the gain of the active 45 on the amplification spectral band, the amplified wave undergoes deformation. A gain flattener filter may be connected to the amplifying element 45 output. In an embodiment of the invention, the filter is created by one or more artificial cladding gratings to couple in a cladding 19

the amplification excess of the wave E. The sampling device is used as a filter as it permits the wave non transmitted by the core 17 to be recovered at the output of the cladding 19. A recovery and treatment element of the wave C is optically connected to the end 19b of the cladding while the output wave S is available at the output of the core 17.

[00169] As the non transmitted light energy C of the wave is proportional to the energy S transmitted, by the core 17, the measurement of the energy guided in the cladding mode(s) permits the output power level of the amplifier to be controlled.

[00170] This control may be useful when a constant level of amplification in time is desired.

[00171] The use of the non transmitted signal by the core 17 may be lost. The control of the output power level of the amplifier does not require any additional coupler type components to carry out the sampling and does not introduce any output losses. In Figure 8, the sampling device and the amplifying element are made in the same substrate. However, these two elements may be made in two substrates that are different or the same. The amplifying element can be an amplifying fibre connected to the sampling device made in a substrate.

[00172] Figure 9 shows in a cross section, another application of the sampling device pour the spectral control of a linear filter.

[00173] In this figure, a source 60 with a wide spectrum 61 (shown close to the source) is optically connected to a guide core 62 made in a substrate 15. The core 62 guides the signal from the source to an optical fibre 63 comprising a Bragg grating 64. The Bragg grating 64 reflects a fine spectral band 65 (shown close to the grating 64) in the fibre 63. The spectral band signal 65 then returns into the substrate 15 by a guide core 66 made in the said substrate.

The core 66 transports this signal to a sampling device 67 of the invention.

[00174] In this example, the device 67 is of the same type as that shown in Figures 7a and 7b. The strip of photo detectors 50, for example a CCD strip, is connected to the ends of the cladding and the core of the sampling device and measures the filtered signals I_1 and non filtered signals I_2 of the zone of interaction. A central analysis unit 69 is for example connected to the strip 50 to treat the signals measured.

[00175] When the Bragg grating 64 is subjected to parameter variations (temperature, constraints, etc.) the reflected wavelength varies. The signal measured at the output of the sampling device thus permits the value of this variation to be determined.

[00176] The sampling device according to an embodiment of the invention permits functions to be created by modifying the various elements of the artificial cladding grating. The artificial cladding grating permits a linear signal to be transmitted depending on the wavelength at a given range. Thus, if λ_m is the central wavelength of the filter, the transmission is given for a relationship of the following type close to this wavelength:

$$T(\lambda) = a \text{ x } (\lambda - \lambda_m) + t_m \qquad (3)$$

[00177] If the signal transmitted I_2 and its complementary signal I_1 are measured simultaneously in decibels (for example, by using a CCD strip) and that the two are separated, we the following relation is obtained:

$$I_2^{dB} - I_1^{dB} = 10 \log(1 - t_m - a \text{ x } d\lambda - 10 \log(t_m + a \text{ x } d\lambda) \qquad (4)$$

[00178] Thus, contrary to the prior art, the double detection is carried out in the same device, which allows the measurement to be made insensitive to intermediate losses and insensitive to fluctuations of intensity of the measurement.

[00179] Furthermore, the use of an artificial cladding grating allows to perform both the filtering function as well as sampling. This results in a gain in cost and space.

[00180] To resolve any possible problems of non linearity of the measurement depending on the spectral offset, the spectrum of the component may be adapted. Thus, if desired:

$$I_2/I_1 = \alpha \times d\lambda + \beta_m \qquad (5)$$

[00181] The response of the sampling device simply needs to be adjusted so as to have a defined transmission on the useful spectral band with the equation:

$$T(\lambda) = \frac{1}{1 + \alpha \times (\lambda - \lambda_m) + \beta_m} \qquad (6)$$

[00182] This system may be applied to the frequency control of a fine source or the offset measurement of Bragg grating sensors.

[00183] In the following paragraphs, an embodiment is described in conjunction with Figures 10a to 10d, using the ion exchange technology, of a zone of interaction I used in a sampling device according to an embodiment of the invention.

[00184] These figures are cross sections of the zone I in a plane xy.

[00185] Thus, Figure 10a shows the substrate 15 containing beforehand B ions. A first mask 71 is created for example by photolithography one of the faces of the substrate. This mask comprises an opening determined according to the dimensions (width, length) of the cladding 19 that are to be obtained.

[00186] A first ionic exchange is carried out between the A ions and B ions contained in the substrate, in a zone of the substrate situated close to the opening of the mask 71. This exchange is obtained for example by soaking the substrate along with the mask in a bath containing A ions and by optionally applying an electrical field between the face of the substrate on which the mask is positioned and the opposite face. The zone of the substrate in which this ionic exchange takes place forms the cladding 19.

[00187] To bury this cladding, a step of re-diffusing the A ions is carried out with or without the help of an electrical field applied as previously described. Figure 10b shows the cladding after a step where it is partially buried. The mask 71 is generally removed prior to this step.

[00188] The creation of the cladding of the invention is therefore similar to the creation of a guide core but with different dimensions.

[00189] The following step represented in Figure 10c comprises forming a new mask 75 on the substrate for example by photolithography possibly after cleaning the face of the substrate on which it is made. This mask comprises patterns capable of permitting a guide core 17 to be made. When the core comprises a grating, the mask patterns 75 may be adapted to the grating patterns to be formed.

[00190] A second ionic exchange is then carried out between the B ions of the substrate and the C ions which may or may not be the same as the A ions. This ionic exchange may be carried out as previously described by soaking the substrate in a bath containing C ions and by optionally applying an electrical field.

[00191] Finally, Figure 10d shows the component obtained after burying of the core 17, obtained by re-diffusion of the C ions and final burying of the cladding, with or without the

use of an electrical field. The mask 75 is generally removed prior to this burying step.

[00192] The conditions of the first and second ionic exchanges are defined so as to obtain the desired differences in the refractive indices between the substrate, the cladding and the core. The adjustment parameters of these differences are in particular the exchange time, the temperature of the bath, the concentration in ions of the bath and the presence or absence of an electrical field.

[00193] In one embodiment, the substrate 15 is made of glass containing Na^+ ions, the mask 71 is made of aluminium. If the cladding is uniform, the mask 71 has an opening of about 30 µm in width (the length of the opening depends on the desired length of cladding for the desired application.

[00194] The first ionic exchange is performed with a bath comprising Ag^+ ions at a concentration of approximately 20%, at a temperature of around 330°C and during an exchange time of about 5 minutes. Re-diffusion of the ions first takes place in open air at a temperature of about 330°C for 30 s, then the cladding is partially buried in the glass. This burying is carried out for a re-diffusion in a sodium bath at a temperature of about 260°C for 3 minutes.

[00195] The mask 75 is also made of aluminium and has an opening pattern of about 3 µm in width (the length of the pattern depends on the desired core length for the desired application).

[00196] The second ionic exchange is performed with a bath also comprising Ag^+ ions at a concentration of about 20%, at a temperature of about 330°C and for an exchange time of about 5 minutes, with a re-diffusion of the ions first taking place in open air at a temperature of about 330°C and for 30 s. Then the core thus formed in the glass is partially buried by re-diffusion in a sodium bath at a temperature of about 260°C for 3 minutes.

[00197] The cladding and the core are finally buried under an electrical field, with the two opposite faces of the substrate in contact with two baths (in this example of sodium) capable of allowing a difference in potential to be applied between these two baths.

[00198] It must be appreciated that many variants of the previously described process may be made.

[00199] To bury the cladding and the core, a variant of the process consists of depositing on the substrate 15, a layer of material 78, shown in dotted lines in Figure 10d. To allow optical guiding, this material has a refractive index lower than that of the cladding.

[00200] The fabrication of the component of the invention is not limited to the ion exchange technique. The component of the invention may be made by all techniques which permit the refractive index of the substrate to be modified.

[00201] Furthermore, as discussed previously, the period, the size, the position of the grating created, with respect to the core and the cladding, are parameters which can be adapted to suit specific applications.

[00202] The pattern of the grating can be defined on the mask permitting the cladding to be created and/or on the mask permitting the core to be created or solely on the mask permitting both the cladding and the core to be created or on a specific mask solely for the creation of the grating.

[00203] Figures 11a to 11d show examples of embodiments of masks M1, M2, M3, M4 permitting an elementary grating to be created. These figures are elevation views of masks and only show the part of the masks permitting the grating to be created. The white zones of the pattern of the masks are the openings of the masks.

[00204] These masks permit a periodic grating of period Λ to be obtained. The mask M4 permits a grating to be obtained for segmentation while the masks M1 and M2 permit a grating to

be obtained for variation of the width of the patterns. Furthermore, the mask M3 permits a grating to be obtained for the introduction of a periodic disruption P in the substrate for example next to the core 70.

[00205] The previous figures show examples of gratings formed in the guide core.

[00206] Figure 12 shows an elementary grating 80 created for segmentation in a zone of interaction, both in the core 17 and in the cladding 19, according to an embodiment of the present invention.

[00207] Thus, in Figure 12, the grating 80 is formed in the cladding 19 by alternating the period Λ of zones 82 of variable lengths (in the direction z of propagation of a light wave). As the core is included in the cladding, at least in the zone of interaction, the grating is also included in the core. In other words the core also comprises refractive index zones that are different from that of the rest of the core.

[00208] The gratings may be formed by all of the conventional techniques permitting the effective index of the substrate to be modified locally in the core and/or in the cladding.

[00209] The gratings may be created during ionic exchanges permitting the core and/or the cladding to be created or during a specific ionic exchange. The gratings may also be obtained by etching the substrate in the zone of interaction or by irradiation. In particular, the gratings may be obtained by exposure of the core and/or the cladding to a CO_2 type laser. By producing localised heating, the laser allows ions to be re-diffused locally and thus create the grating pattern.

[00210] For example, the substrate can be scanned with a laser beam modulated, for example, in amplitude so as to introduce modulation in the grating to the desired pitch.

[00211] The pattern of the grating depends on the targeted applications. In particular, the grating may have a variable period (chirped grating) or variable efficiency (apodised grating).